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Large Eddy Simulation of Turbulent Channel and Jet Flows using the Approximate Deconvolution Model

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Abstract

In the frame of the present work, Large Eddy Simulations (LES) of turbulent low-Mach number flows were performed. The work is part of an extended project with the goal of establishing LES for turbulent reacting flows.

The goal of the present work was the combination of a spectral element code, which in the past was used for Direct-Numerical Simulations (DNS), and the Approximate Deconvolution Model (ADM) as a subgrid model for LES. The spectral element method combines high accuracy with the flexibility for handling complex geometries.

ADM was first implemented for incompressible, turbulent flows and validated for a turbulent channel flow at Reynolds numbers $Re = 2,800$ and $Re = 10,935$. The flow in the doubly periodic (stream- and spanwise directions) channel was forced at the inflow, maintaining a constant mass flux. Good agreement was obtained between the LES and the DNS results of Moser et al. (R. D. Moser, J. Kim, and N. N. Mansour, Direct numerical simulation of turbulent channel flow up to $Re_{\tau} = 590$, Phys. Fluids, 11(4):943-945, 1999) with respect to the friction Reynolds number and the Reynolds and shear stresses and the logarithmic law of the wall. The spatial resolution especially at the wall is comparable with the LES of Stolz et al. (S. Stolz, N. A. Adams, and L. Kleiser, An Approximate Deconvolution Model for Large Eddy Simulations of compressible flows and its application to incompressible wall-bounded flows, Phys. Fluids, 13(4):997-1015, 2001).

In the original version of the model, the relaxation term of ADM is used to account for the interaction between the large and the small scales of the turbulent flow and is based on low-order statistics. An alternative formulation, based on higher-order statistics was proposed by Yakhot (private communication, 2002). He proposed a relaxation term based on
low-order statistics and a correction based on the local value of the rate of strain. This model was implemented in a global spectral-LES code. It was found that with this modification the logarithmic wall law and the friction Reynolds number ($Re_τ$) were almost insensitive to the spatial resolution in stream- and spanwise directions and the spatial resolution in wall-normal direction could be significantly reduced with respect to that of the standard ADM.

The incompressible LES code was then used for turbulent jet flows for $Re = 2,000$. The setup is that of a jet issued from a nozzle of diameter $d_j$ into a co-flowing stream in a domain of diameter $11d_j$ and length $40d_j$. The domain is bounded moving with the velocity of the co-flowing stream. The jet flow is perturbed with correlated velocity fluctuations and the goal was the investigation of the scale-similarity region ($x/d_j > 20$). The LES results were compared with DNS simulation results performed for this project. The investigation shows an overestimation of the centerline turbulent velocity intensity in the transition region ($x/d_j < 20$), whereas a good agreement was obtained in the scale-similarity region. Two different LES filters were investigated. The first filter (Boyd filter) filters the spectral element excluding the elemental boundaries and the second filter (Legendre filter) filters it including the elemental boundaries. The agreement of the turbulent velocity intensity in the scale-similarity region with the DNS result was only obtained with the second filter. Further, a variation of $Re$, different mean velocity profiles at the exit, different correlation of the inflow perturbations, different values of the relaxation parameter of ADM, different filter types for the explicit LES filtering and an alternative formulation of the filtered conservation equations could not eliminate the overestimation of the turbulent intensities. Summarizing, the combination of the spectral element code and ADM shows satisfying results in the scale-similarity region whereas the turbulent intensities are overestimated in the transition region ($x/d_j < 20$).

The LES code was then extended for variable-density, low-Mach number flows and was validated against DNS results computed for a non-isothermal, single-species jet. The same setup was used as for the isothermal jet with $Re = 2,000$ and the length of the domain was set to $20d_j$. The Boyd and the Legendre filter were investigated and the LES with the Legendre filter were unstable whereas the Boyd filter stabilized the simulation. Overall the turbulent intensities for velocity
and temperature and the decrease of the mean quantities along the centerline were overestimated by the LES.
Zusammenfassung


Die originale Version von ADM wird ein Relaxationsterm verwendet,


Der Code wurde anschliessend weiterentwickelt für die Grobstruktursimulation von nicht-isothermen, turbulenten Freistrahl-Strömungen. Dabei wurde das Rechengebiet des isothermen Freistrahls auf eine Länge